

Comparison of ZVI Treatment Zones and Standard PRBs as Groundwater Containment Barriers

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Introduction

Barriers to contaminant migration are very often one component to a complete remediation approach for sites. These barriers are typically designed to reduce or eliminate the transport of contaminants downgradient (in other words, control contaminant migration). Of the many barrier approaches, hydraulic/physical containment systems and permeable reactive barriers (PRBs) are the most common approaches in use today. Zero valent iron (ZVI) PRBs have become an almost standard approach for containment of chlorinated solvents and some metals.

ZVI-treatment zones are a potential alternative to standard ZVI-PRBs. ZVI-treatment zones are created by installing a line of overlapping ZVI injection points. A highly reactive ZVI powder is injected into the subsurface using pneumatic fracturing followed by pneumatic injection.

This paper briefly describes the ZVI-treatment zone approach, presents a case study, and compares ZVI-PRBs with ZVI treatment zones.

ZVI Treatment Zone Background

At the heart of the ZVI-treatment zone approach is the techniques used to inject the ZVI into the subsurface. ARS Technologies, Inc., has developed a method using two patented technologies:

- Pneumatic Fracturing Technology – Injection of a gas to create fractures and enhance the overall bulk hydraulic conductivity of the formation
- FeroxSM – pneumatic atomization injection of ZVI powder

The FeroxSM process involves injection of ZVI powder under pressure, normally in a water-based slurry form, along with a nitrogen gas stream. Pneumatic fracturing of selected intervals is usually completed prior to injection to facilitate distribution of the injected materials, especially in low-permeability media. The multi-phase fluid stream (water and nitrogen gas) delays premature oxidation of the iron particle surfaces, keeps the iron particles in suspension, and provides moisture (in the unsaturated zone) necessary for the desired reaction.

The injection process uses an inflatable packer system to isolate (and fracture) discrete subsurface intervals for injection of the materials. It also involves a unique liquid atomized injection system, whereby a specialized nozzle turns the injected fluids into an atomized mist in order to more efficiently disperse into the target zone. The injection nozzles are capable of delivering the atomized fluids in a 90-degree or 360-degree pattern. Figure 1 illustrates the equipment used in ZVI injection.

The injection method can be used to inject ZVI powder into a source area, throughout the aerial extent of a plume, or in a line of overlapping injection points perpendicular to the groundwater flow direction. This line of wells creates a ZVI-treatment zone to treat contaminants migrating offsite and thereby serve as a barrier to contaminant migration.

Figure 2 illustrates a potential layout of a ZVI-treatment zone, in this case, as proposed for a pilot study. The ZVI injection points can be spaced from 15 to 30 feet apart. The number of rows of injection wells will depend on the required retention time, which is a function of the concentration of contaminants and the groundwater flow

velocity. The ZVI injection can be designed to result in a maximum iron concentration of 1 to 2 percent by weight (iron to soil mass) within the treatment zone.

Case Study

ZVI injection was performed at Marshal Space Flight Center (MSFC), which is located in northern Alabama within Redstone Arsenal (RSA). Past solvent management practices during the 1960's era of rocket engine testing resulted in groundwater contaminated with chlorinated volatile organic compounds (CVOCs) beneath most of the MSFC facility. The presence of unexploded ordnance limits the application of technologies that required significant subsurface disturbance (such as PRBs)

The facility subsurface consists of a low-permeability clayey residuum overlaying karst bedrock. The majority of contaminants are believed to lie within the basal layer of the residuum, called the rubble zone, that transitions into the underlying bedrock. The ZVI injection was performed at source area 2 (SA-2) at MSFC. SA-2 is contaminated by high levels of trichloroethene (TCE). The highest TCE concentration observed in the rubble zone groundwater beneath the source area was 72,800 µg/l.

ZVI injection was performed in the source area and a ZVI-treatment zone was also created at the downgradient edge of the plume. Approximately 11,000 pounds of ZVI were injected, achieving an aggregate, estimated iron-to-TCE ratio of 200:1. Follow-up sampling showed iron impregnation of the subsurface matrix. Pressure readings and field measurements for iron during injection indicated that the radius of influence ranged from 20 to 60 feet. Groundwater conditions were changed from an aerobic, non-reducing state to anaerobic, reducing conditions.

The monitoring wells in the source zone provide evidence of the reduction reactions caused by the injected ZVI. TCE concentrations in the main source area monitoring well was reduced from 72,800 to 7,600 µg/l (about 90-percent reduction) over the initial 20 months. Production of chloride, vinyl chloride, methane, ethene, ethane, and carbon dioxide have been observed in the main source area monitoring well. A chloride balance of about 97 percent has been calculated, suggesting that CVOc degradation is occurring.

Although only limited data is currently available to draw conclusions, it appears that the ZVI treatment zone is effective in reducing downgradient contaminant migration. For example, chloride concentrations are increasing at downgradient monitoring points without increases in TCE concentrations. One of the challenges in evaluating the performance of a ZVI-treatment zone is the long time it takes for groundwater to move through the treatment zone and show up in a monitoring well. For example, at this site, chloride concentrations did not start to increase in the downgradient wells until after about 18 months.

Comparison Between ZVI-PRBs and ZVI Treatment Zones

The following summarizes a number of key issues with the application of ZVI-PRBs and ZVI-treatment zones:

- **Fundamental Difference**
 - ZVI-PRBs greater than 20% iron in the wall (typically 3 ft wide)
 - ZVI Treatment Zones approximately 1% (minimum of 20 ft wide)
- **Chemistry:** Basically the same, but reducing conditions in ZVI Treatment Zone are not as strong
- **Predicted Performance**
 - ZVI-PRB: provide an "engineered" treatment wall of uniform consistency - less chance for untreated pass through
 - ZVI-Treatment Zone: less control on distribution of ZVI, greater chance for untreated pass through
- **Available Performance Data**
 - ZVI-PRB significant quantities of data (75 plus applications over 10 plus years)
 - ZVI-Treatment Zones, little data is available, due in part to the limited number of applications (10 plus applications over about 4 years) and the slow movement of groundwater (e.g. takes years to get meaningful data)

- Cost
 - ZVI-PRB: \$2 to \$3 M per 1,000 linear ft, 40 ft deep
 - ZVI-Treatment Zone: \$2 to \$3 M per 1,000 linear ft, 40 ft deep
- Impact of Utilities and Disruption to Facilities
 - ZVI-PRB: May have significant constructability issues
 - ZVI-Treatment Zones: less impact
- “Cuttings”/Waste Disposal
 - ZVI-PRB: Maybe a significant issue (cost?)
 - ZVI-Treatment Zone: Less of an issue
- Life of the ZVI
 - ZVI-PRB: Maybe limited by fouling
 - ZVI-Treatment Zone: Not likely to be limited by fouling, but could be limited by reactive iron mass, with high contaminants loads
- Impact of Depth
 - ZVI-PRB: Limited by trenching equipment (possibly 70 ft)
 - ZVI-Treatment Zone: Only limited by depth of drilling equipment

In summary, ZVI treatment zones offer an alternative to standard ZVI-PRBs. They may have advantages over ZVI-PRBs in certain situations, such as deep installations or where significant constructability issues are present with ZVI-PRBs.

References

ARS Technologies, Inc. [http:// www.arstechnologies.com](http://www.arstechnologies.com).

CH2M HILL Project Website (Public Access): <http://www.ch2m.projects.com/nasa>. (User Name: nasa_huntsville; Passcode: insitu.). In-Situ Treatability Study Projects.

Figure 1. ZVI Injection Method

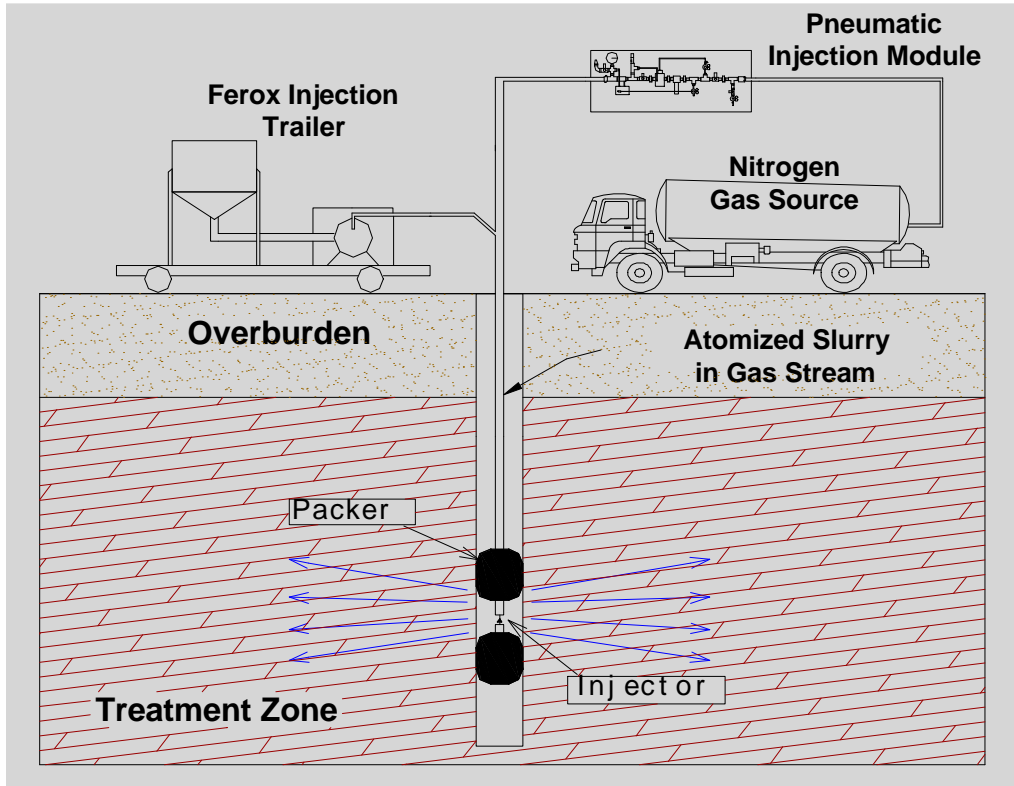


Figure 2 – Example Layout of a ZVI Treatment Zone

